CHAPTER 7

INDIGENOUS BIOMASS ENERGY SOURCES

7.1 PRESENT BIOMASS AND BIOENERGY PRODUCTION

This Section discusses existing biomass production and conversion in the state.

7.1.1 LOCATION, TYPE, AND YIELD OF AGRICULTURAL CROPS AND RESIDUES

Crops assessed in this investigation include sugarcane, pineapple, macadamia nuts, other fruits, field crops, grazing crops, coffee, aquaculture, and forest. Of these, only crops that are produced in substantial quantities and yield significant residues that are presently being used for energy or potentially could be used for energy are discussed here. Since municipal solid wastes (MSW) and animal wastes represent significant sources of energy that can have sizable disposal costs that might serve as credits (via "tipping fees") to offset collection and processing costs, they are logical candidates for energy production (and in some cases already are being used successfully) and therefore are inventoried along with crops and crop residues. The amounts of major biomass residues and their energy value are summarized in Table 7-1. The total amount of residues produced in the state is 3.8 million tons per year.

Sugarcane residues, comprised of bagasse (milled sugarcane fiber, which presently is being almost fully utilized, although often at less than optimal efficiency) and "cane trash" (mostly extraneous material, burned in the field), represent by far the largest resource. In 1991, 1.7 million tons of sugarcane residues was available in the field. Studies (e.g., Kinoshita, 1988) suggest that approximately 35 percent of the fiber in standing sugarcane is consumed in open-field burning of cane, leaving only about 1.1 million tons of fiber (in bagasse) at the factory, nearly all of which is used as boiler fuel. Municipal solid waste (also already being utilized to a large extent for energy purposes), at 1.2 million tons per year with approximately 65% organic content (McCabe, 1994), represents the state's second largest biomass residue resource. The energy contributions of other crop residues and animal wastes are relatively modest.

In total, the energy value of all biomass residues presently being produced in the state is less than 0.04 quad. While this is a substantial amount of energy, it represents only approximately 10 percent of the energy presently consumed in the state, and to a large extent already is being converted, mostly into electricity. Thus, if biomass is to displace a major portion of the fossil fuels imported into the state, the resource tapped would have to be dedicated feedstocks produced specifically for energy conversion rather than crop residues.

7.1.2 PRESENT USE OF CROPS AND RESIDUES

Disposition of the above mentioned biomass residues is summarized in Figure 7-1. Except for sugarcane and municipal solid wastes, biomass residues are not used extensively for conversion purposes. For example, most of the pineapple residue after harvesting is burned

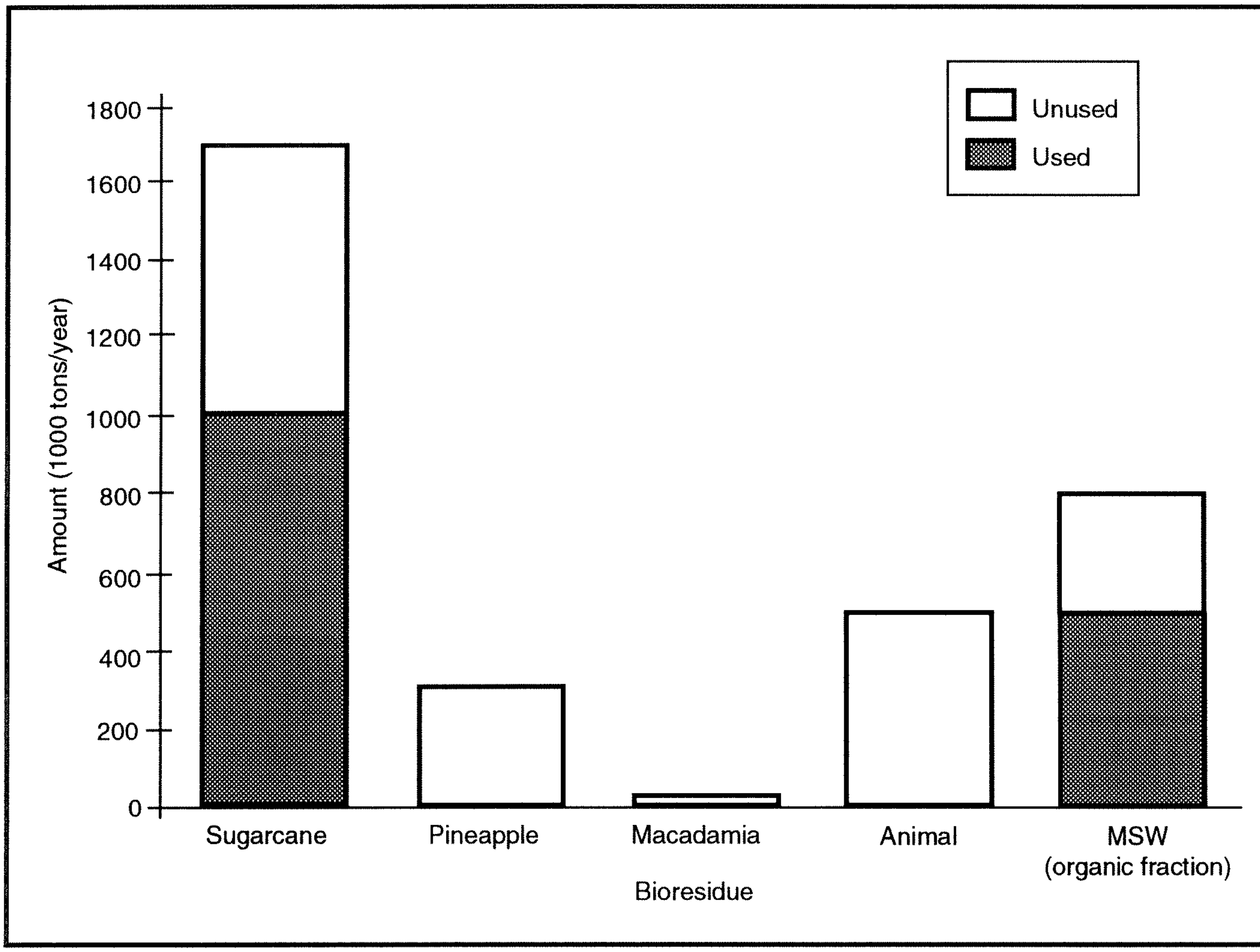
Table 7-1

Amount and Energy Value of Biomass Residues Produced in Hawaii, 1991

Biomass Resource	Annual Output (1,000 tons)	Energy Potential (1,000 joules/yr)	(%)
Sugarcane residues	1,696	29,036	67
Pineapple residues	313	4,891	11
Macadamia nut hulls	14	230	1
Animal wastes	505	512	1
Municipal solid waste	1,242	8,583	20
Total	3,770	43,252	100

Figure 7-1

Disposition of Biomass Residues in Hawaii, 1991
(All Tonnages Are Given on Dry Bases Except for MSW and Animal Wastes)



in the field or plowed under; and only a portion of macadamia residues are used for process heat.

7.1.3 EXISTING BIOMASS-FOR-ENERGY (FUEL OR ELECTRICITY) CONVERSION FACILITIES

Biomass makes a far greater contribution in serving the energy requirements of the state than any other non-fossil resource in Hawaii. Most of the biomass conversion facilities in the state are cogeneration facilities that produce process heat and electricity. A graphical database (see Appendix A-5) contains details on the various biomass-for-energy conversion facilities in the state.

The sugar industry is the largest converter and user of biomass energy in the state. In 1991, approximately one million tons of sugarcane bagasse (dry basis), having an energy value of $17x10^{12}$ British termal units (Btu), was consumed in sugar factory cogeneration plants. The gross amount of electricity attributable to that quantity of bagasse was approximately 500,000 MWh, and, considering the very efficient manner in which heat is used in processing cane into sugar (including, for example, the use of multiple-effect evaporators and extracted steam for mechanical drives), the amount of process energy attributable to that bagasse is exceedingly high. The difference between the amount of bagasse consumed (approximately 1 million tons, dry basis) and the amount of sugarcane residue actually produced (1.7 million tons, Figure 7-1) is attributable to sugarcane fiber consumed in open-field burning of cane and in fiber used for other purposes.

A large converter of non-crop-related biomass into marketable energy in the state is the "Honolulu Project of Waste Energy Recovery" (H-POWER) MSW conversion plant on Oahu. In 1991, more than 600,000 tons of MSW (roughly one-half of the 1,200,000 tons produced in the state) was processed by H-POWER, with most of the MSW being converted into refused-derived fuels (RDF) and then into 370,000 MWh (gross generation; net sale to the utility company was 320,000 MWh) of electricity.

Another significant non-crop-related biomass-for-energy project in the state is the Kapa'a Generating Partners' sanitary landfill gas recovery project, which taps 2.3 million cubic feet of gas generated daily in an 85 acre landfill in Kailua, Oahu, and, in doing so, generates process heat and 10,000 MWh (1993) of electricity via a 3.2 MW gas turbine generator.

One biomass-for-energy conversion pilot project of potentially major significance, presently under construction, is the biomass gasifier scale-up facility at the Paia sugar mill on Maui (Overend et. al., 1992). That project, funded primarily by the U.S. Department of Energy and the State of Hawaii, seeks to scale-up biomass gasification technology with the goal of using that technology for the production of electrical power and transportation fuels. The first phase, underway, calls for designing, constructing, and operating a scaled-up biomass gasification plant; assessing environmental impact; and developing a centerpiece for continuing research on biomass gasification and for evaluating commercial applications for the product gas. Follow-on phases in this program include upgrading the product gas for use in a gas turbine-electrical generator (Phase 2) and for catalytic conversion into a liquid transportation fuel (Phase 3). The Maui biomass gasifier facility presently is intended to process 50 tons (dry basis) per day of biomass. During the next phases of development, it will be modified to process 100 tons per day.

The other biomass conversion plants in the state are much smaller in scale than those mentioned above and are not discussed here.

7.2 POTENTIAL BIOENERGY PRODUCTION

7.2.1 ENERGY CROPS

7.2.1.1 Candidate Energy Crops

The species of plant selected for conversion into transportation fuels would depend on its suitability to local conditions, yield, cost of production and delivery, type of transportation fuel to be produced, and conversion technology to be employed. Sugarcane grown commercially in Hawaii is one of the best crops in producing biomass dry matter, and has advantages over most other energy-crop candidates, including well developed infrastructure, cultivation and harvesting technologies. Moreover, it is likely that if sugarcane cultivars and agronomic practices were adopted to maximize biomass yield rather than sugar yield, significantly higher biomass productivities could be obtained (Osgood and Dudley, 1993). Owing to the high yield and yield potential of sugarcane, and its existing infrastructure and inherent advantages in producing fermentation products such as fuel ethanol, sugarcane is one of the obvious energy crop candidates considered in this investigation.

Several high-fiber-yielding tree and grass species have been considered as possible short-rotation, intensive-culture (SRIC) energy-crop alternatives to sugarcane. Although some of these alternative crops have yield potentials that might exceed that of sugarcane, experience in growing and harvesting most of these alternative crops in Hawaii generally is less extensive than with sugarcane. Also, because these crops produce essentially only fiber, they may not offer the same opportunities or productivities for fermentation products as would sugar-bearing crops such as sugarcane.

One of the critical factors impacting the economic viability of biomass-for-energy is the yield potential of a crop species under optimum cultivation practices. Numerous biomass experiments have been performed in Hawaii which have identified a number of promising high-yielding species of trees and grasses. Most of those species have the potential to be refined into energy, fiber, or chemical products. Because of their high yields and versatility, *Eucalyptus* and *Leucaena* offer the best commercial potential of the tree species. Napiergrass (*Pennisetum purpureum*) has been found to have the greatest yield potential and the strongest commercial potential of the grass species.

The grass and tree crop yields used in this study were projected from experiments conducted by the Hawaiian Sugar Planters' Association at Hoolehua, Molokai and elsewhere in the state.

At Hoolehua, seven crops (one plant crop and six ratoon crops[1]) of banagrass (a variety of Napiergrass) were harvested over a 4.3 year period. Yield results are presented in Table 7-2. The cumulative dry-matter yield over the seven crops was 84 tons per acre, giving an average yield of 19.8 tons per acre-year.

Ratoon crops of banagrass yielded more than twice the plant crops in another Hawaiian Sugar Planters' Association study which included five locations (Table 7-3). Fiber content in the ratoons was 29.6 percent, whereas plant crops contained only 18.9 percent fiber. The average yield for plant crops was 18.5 tons per acre-year; by contrast, the ratoon crops averaged 42.1 tons per acre-year.

Two tree yield experiments were conducted on Molokai by the Hawaiian Sugar Planters' Association. Tree height and diameter were measured in a two-year study at Hoolehua, Molokai. Tree yield was estimated based on the height and diameter. The dry matter yield for *Leucaena* "K636" planted at 1 meter by 1 meter spacings, 4,000 trees per acre (10,000 trees per hectare), was 9.3 tons per acre-year. A five-year study involving wider spacings, 2 meters by 2 meters, 1,000 trees per acre (2,500 trees per ha), was also conducted with *Leucaena* "K636," which gave a yield of 8.6 tons per acre-year. Another five-year study on Maui with the same species produced 8.4 tons per acre-year.

The yield of banagrass was about twice the yield of *Leucaena* in the Hawaiian Sugar Planters' Association Molokai studies; however, the banagrass was harvested seven times while the *Leucaena* was harvested only once. More frequent harvests of *Leucaena* probably would have resulted in higher yields but with higher moisture content.

The growth of *Eucalyptus* and *Leucaena* from seedling populations have been highly variable in growth rate and form. The selection of superior trees and the development of their clones offers a potential method of rapidly increasing productivity and uniformity of biomass plantations. Clonal plantations of *Eucalyptus grandis* have been established in Brazil, Africa, India, and California. In Brazil, Aracruz Florestal has nearly doubled its yields by using selected clones instead of unimproved seedling stock. A *Leucaena* breeding program, designed for maximum biomass productivity, might be able to provide incremental gains of 5-10 percent per generation.

7.2.1.2 Land Availability And Suitability

7.2.1.2.1 Land Availability

In this section, land availability refers to the relative accessibility of land for energy cropping from the legal standpoint. The availability of land for biomass-for-energy production in the state is dictated primarily by zoning. However, the actual use of agricultural land and the ownership of land can provide insight on whether the land might be immediately available for biomass-for-energy production and on potential barriers preventing its use for such purposes; therefore, present use and ownership of land also are discussed here.

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[1]A ratoon crop is produced by using the stalk or shoot arising from the root or crown of a perennial plant.

Table 7-2

Banagrass Yields (Dry Matter) at Hoolehua, Molokai

Harvest Number	Harvest Date	Crop Days	Yield[1] (Tons/Acre)	Dry Matter[1] (Tons/Acre Year)	Season
1	4/20/87	217	6.87	11.55	Winter
2	11/8/87	212	15.8	27.21	Summer
3	5/24/88	188	9.69	18.81	Winter
4	2/22/89	289	15.83	20.35	Winter
5	8/23/89	176	15.1	31.32	Summer
6	4/3/90	223	8.87	14.51	Winter
7	1/8/91	280	11.61	15.13	Winter
Average		226.43	11.97	19.84	

Source: Hawaiian Sugar Planters' Association data

Note:

1) Plots of 40 feet x 40 feet were hand harvested. Three replications were harvested at each date from a 0.7-acre planting.

Table 7-3

Dry Matter Yields of Plant Versus Ratoon Crops for Banagrass at Five Locations in Hawaii

Location	Yield (Tons/Acre)		Yield (Tons/Acre-Year)	
	Plant	Ratoon	Plant	Ratoon
Mauna Kea Agribusiness Co.	12.91	36.14	18.84	47.52
HC&S Co.	10.09	31.61	17.04	41.64
McBryde Sugar Co.	8.39	29.62	15.24	32.04
The Lihue Plantation Co.	9.56	39.35	17.4	42.48
Waialua Sugar Co.	12.05	35.32	24.12	47.04
Average	10.6	34.41	18.53	42.14

Source: Hawaiian Sugar Planters' Association data.

Zoning

The six largest islands in the state (Hawaii, Maui, Oahu, Kauai, Molokai, and Lanai) cover 4.0 million acres (1.6 million hectares) with diverse geographical and environmental characteristics. Hawaii is the only state in the nation with statewide land-use designations; these include: Conservation, Agricultural, Urban, or Rural, as determined by an appointed Land Use Commission.

The graphic database (Appendix A-5) presents detailed maps showing the land designations for the six major islands. Table 7-4 summarizes the land designations for the four counties and the entire state. Only lands classified as Agricultural or Conservation are considered as potentially available for energy crop production (although practically speaking, a large fraction of the land designated Conservation would not be available for crop production owing to environmental and cultural concerns). Conservation and Agricultural lands represent the two largest land designations in the state, comprising 2,000,000 and 1,900,000 acres (800,000 and 760,000 hectares), or 49 percent and 46 percent, respectively, of the total land area.

The island of Hawaii, with 1,200,000 acres (490,000 hectares) of Agricultural land, has nearly twice as much land zoned Agricultural as the remainder of the state combined. Maui, with nearly 250,000 acres (100,000 hectares), has the second largest acreage zoned Agricultural; Kauai, Oahu, and Molokai have about 120,000 acres (50,000 hectares) each zoned Agricultural; and Lanai has less than 50,000 acres (20,000 hectares) of Agricultural land. Each of the four counties regulates Agricultural lands under guidelines established by the Land Use Commission.

Urban and Rural lands comprise only 180,000 and 10,000 acres (73,000 and 4,000 hectares), respectively, about 4 percent and less than 1 percent of the total land area in the State of Hawaii.

Land Use

Appendix A-5 presents detailed maps showing recent uses of agricultural lands for the six major islands. Utilization of agricultural lands in the four counties in the state, summarized in Table 7-5, is categorized as follows (in order of descending acreage): sugarcane, pineapple, macadamia nuts, fruits and vegetables, miscellaneous crops, and coffee.

Only those agricultural uses with agronomic needs that are comparable to energy crops (e.g., intensively cultivated crops) should be considered. Some lands that are not under intensive culture, such as pasture land, often are not well suited for energy crop production because factors needed for high yield (e.g., irrigation water, terrain compatible with mechanization) might not be available.

Table 7-4

Summary of Land Designations in the State, 1991
Zoning - State of Hawaii

Zone	Land Area (1,000 acres)				
	Hawaii	Kauai[1]	Maui[2]	Oahu	Statewide
Agriculture	1,199	147	401	131	1,878
Conservation	1,333	195	296	156	1,980
Rural	1	1	8	0	11
Urban	48	13	21	96	179
Total	2,581	356	726	383	4,048

Notes:
1) The county of Kauai comprises the islands of Kauai and Niihau.
2) The county of Maui comprises the islands of Maui, Molokai, and Lanai.

Table 7-5

Summary of Present use of Agricultural Lands in the State, 1991
Usage - State of Hawaii

Crop	Land Area (1,000 acres)				
	Hawaii	Kauai[1]	Maui[2]	Oahu	Statewide
Sugarcane	56	34	43	23	156
Pineapple			16	13	29
Fruits and Vegetables	7	1	3	2	13
Macadamia nuts[3]					2
Coffee[4]					23
Miscellaneous	2	1	2	1	6

Notes:
1) The county of Kauai comprises the islands of Kauai and Niihau.
2) The county of Maui comprises the islands of Maui, Molokai, and Lanai.
3) Data for macadamia nuts reported separately for each county; only statewide total reported.
4) Data for coffee not reported for each county; only statewide total, excluding Kauai acreage, reported.

Ownership

Land ownership does not directly determine whether a parcel of land is available for energy crop production. However, land ownership can pose restrictions on the timing in which a targeted parcel of land becomes available and the specific use of that land; therefore, land ownership is examined in this investigation. The information is summarized in Table 7-6.

Table 7-6

Summary of Land Ownership in the State, 1991

Ownership	Land Area (1,000 acres)				
	Hawaii	**Kauai**[1]	**Maui**[2]	**Oahu**	**Statewide**
State	941	137	179	54	1,311
HHC[3]	109	19	55	3	187
Federal	223	3	29	52	306
Private	1,308	197	464	275	2,243
Total	2,581	356	727	384	4,047

Notes:
1) The county of Kauai is comprised of the islands of Kauai and Niihau.
2) The county of Maui is comprised of the islands of Maui, Molokai, and Lanai.
3) Hawaiian Homes Commission

Approximately 2,200,000 acres (910,000 hectares), or 55 percent of the land in the state, is privately owned. The majority of the remaining land, 1,300,000 acres (530,000 hectares), about 32 percent of the total area, is controlled by the state; most of state-owned lands are designated Conservation. The Hawaiian Homes Commission (HHC) controls 190,000 acres (76,000 hectares) of land, about 5 percent of the total area. Hawaiian Homes Commission lands are designated Agricultural. The federal government controls over 300,000 acres (120,000 hectares) of land, about 8 percent of the total area, in the state.

Most of the land owned by major landholders in the state is designated Agricultural. While all lands that are designated Agricultural can conceivably be used for energy crop production, much of the lands owned by the various governmental agencies and not presently being used for agriculture would probably not be available. The lands owned by the federal government are mostly being used as national parks, wildlife refuges or by the military, and therefore would not be available. Similarly, much of the lands owned by the state and presently not in agriculture would probably not be available for energy crop production; and a large portion of the county-owned lands are being used for parks and watersheds, and therefore would not be available for energy crop production.

Land Availability Estimation

A methodology for evaluating land availability was developed featuring a classification of five levels of land-use sensitivity (Singh et. al., 1993) varying from Unavailable to Available for crop production. Potential energy-crop lands on four of the five largest islands (excluding Oahu) have been assessed (Phillips et. al., 1992) assuming that only those lands classified as Probably Available (probably available in part, but with concerns in specific areas) or Available (no concerns identified) would be accessible for energy-crop production. The results of this assessment are summarized in Table 7-7.

Table 7-7

Lands Identified as Probably Available and Available for Crop Production on the Islands of Hawaii, Kauai, Maui, and Molokai

Island	Probably Available (Acres)	Available (Acres)	Total (Acres)
Hawaii	368,434	799,386	1,167,820
Kauai	61,776	107,738	169,514
Maui	56,587	214,982	271,569
Molokai	4,201	81,051	85,251
Total for four islands	490,998	1,203,156	1,694,154

Source: Phillips, et.al., 1992

For the islands of Hawaii, Kauai, Maui, and Molokai, the amounts of land considered Probably Available and Available for energy crop production equal 490,000 acres and 1,200,000 acres, respectively, giving a total of 1,690,000 acres. If the land available on Oahu and Lanai are included, it appears that roughly two million acres would be available for energy crop production.

7.2.1.2.2 Land Suitability

Land suitability refers to the ability of a given site to support the production of an energy crop species in a sustainable manner (while economics ultimately determine whether a certain tract of land would be suitable for energy crop production, economic feasibility has not been considered in this assessment of land suitability). The feasibility of short-rotation intensive-culture energy crop production depends largely on the types and amounts of agronomic inputs needed to attain a targeted yield; these are very site specific. Those agronomic factors that determine the suitability of a certain parcel of land to produce energy crops include terrain (elevation and slope), climatic conditions (temperature, rainfall, and insolation), soil characteristics, availability of water, and the like; these are discussed below.

Elevation

Appendix A-5 contains detailed maps showing land elevation for the six major islands. The landscape in the state can be classified into three broad categories: (1) low-elevation lands having altitudes below 500 feet; (2) mid-elevation lands having altitudes between 500 and 1000 feet; and (3) mountains above 1000 feet. Prime agricultural lands generally are found at lower elevations, below 1000 feet, and have rather gentle terrain to facilitate mechanized cultivation and harvesting of crops. Higher elevation lands generally are not good for agriculture, and often are not available for that purpose since they generally are classified Conservation.

Climatic Conditions

Appendix A-5 contains detailed maps showing annual mean temperature, rainfall, and insolation for the six major islands.

The annual mean temperature on Kauai, Oahu, Molokai, and Lanai ranges from 56-77°F; for Maui and Hawaii, with very high elevations, the mean ranges from 44-78°F and less than 40-76°F, respectively. For the six major islands, most locations, other than the mountains, have fairly uniform temperatures, 66-77°F. The agricultural regions on the four lower-elevation islands have temperatures of 62-77°F, and for Maui and Hawaii, those regions have ranges of 60-78°F and 52-76°F, respectively .

Except on the island of Hawaii (along the Hilo-Hamakua coast) and parts of Kauai, most of the prime agricultural lands (i.e., lands presently supporting intensive agriculture) are arid or semi-arid, receiving less than 50 inches of rainfall annually. Regions receiving more than or equal to 100 inches annually largely are classified Conservation. High-yielding energy crops grown in the state would require approximately 100 inches of water annually; therefore, irrigation would be necessary in almost any large-scale commercial biomass-for-energy operation except along the northeastern section (the Hilo/Hamakua coast) and portions of the Puna and Ka'u districts of Hawaii, and smaller contiguous sections on Maui, Oahu, and Kauai.

Insolation in the state ranges from 270-540 langleys (cal/cm2-day). Most of the prime agricultural regions receive high rates of insolation, greater than or equal to 450 langleys; these regions largely coincide with those lands that receive less than 50 inches of rainfall annually. High insolation translates to high yield in energy crops; however, most crops would require some irrigation due to insufficient rainfall in sunny locations.

Soil

Appendix A-5 contains detailed maps showing soil orders on the six major islands.

Ten different soil orders are present in the Hawaiian Islands: (1) Spodosols, (2) Oxisols, (3) Aridisols, (4) Ultisols, (5) Mollisols, (6) Inceptisols, (7) Entisols, (8) Histosols, (9) Vertisols, and (10) Alfisols; much of the mountain regions of each island falls into the category Miscellaneous Land Types. The majority of the lower elevation land mass for the islands of Kauai, Oahu, Molokai, and Maui falls into seven or eight of the above soil orders. For the island of Lanai, only six of these soil orders are present at lower elevations, and for Hawaii, only five (USDA SCS, 1972).

For all major islands except Oahu and Hawaii, most of the lands zoned Agricultural and presently or historically in cultivation contain soils of the Oxisols, Mollisols, Inceptisols and Entisols orders. For Oahu, such lands contain Oxisols, Mollisols, Inceptisols, and Alfisols. For Hawaii, those lands contain Mollisols, Inceptisols, Histosols, and Aridisols (Oxisols are lacking).

The lands covered by Spodosols, Aridisols, and Miscellaneous Land Types generally are considered poor for agriculture. Inceptisols, Entisols, Alfisols, and Ultisols are good for biomass production; the best soils for biomass production are Oxisols and Mollisols. Histosols are organic soils.

Miscellaneous Land Types generally are covered by materials that cannot be classified as soils (e.g., by materials such as rocks or stones, or recently deposited materials). Aridisols are desert soils with very low moisture and organic matter contents. Aridisols often occur in narrow belts along the leeward coast of islands; accumulation of salts in the soil might make these soils problematic for biomass production.

Inceptisols are young soils deficient in phosphorus and thus require relatively high fertilization for high crop yield. Such soils have high infiltration rates, and erosion would be slight to moderate, depending on the degree of slope. Inceptisols are found in abundance on most islands. Although Entisols are not ideal for biomass production, they are used in cultivation of sugarcane and vegetables, and for pasture in Hawaii. Ultisols are highly weathered soils with low to moderate natural fertility, but are very responsive to soil management. These soils are very stable and have good water infiltration rates; leaching of soluble nutrients is likely. Entisols and Ultisols are abundant on Kauai, Molokai, Maui, and Lanai.

Oxisols are the most weathered soil, with very high clay content (up to 90 percent in Hawaii). This soil type covers large areas on all islands, except Hawaii. When properly managed, Oxisols are highly productive. Oxisols have high permeability and leaching of soluble plant nutrients, and moderate water retention.

Mollisols are dark-colored, base rich mineral soils, relatively high in organic matter. Mollisols are excellent agricultural soils with natural fertility (although this varies according to weather conditions). Mollisols are found in quantity on all islands.

7.2.1.3 Potential Lands For Bioenergy Production

The identification of land that might potentially be used for energy crop production is largely an academic exercise. Indeed, much of the 3.9 million acres (1.6 million hectares) of land presently zoned Agricultural or Conservation (note, one-half of this land mass would be nearly two million acres, which would roughly match the acreage deemed "Available" in Section 7.2.1.2.1, with Oahu land included) could be used for the cultivation of energy crops if economic, political, social, and environmental conditions were favorable. This potentially could supply the 0.3 quad (1 quad = 10^{15} Btu or 10^{18} J) of energy presently consumed in the state for transportation and electricity (Department of Business, Economic Development and Tourism, 1994). (A conservative estimate of the energy potential of energy crops from two million acres of land deemed available might assume a yield of 10 tons of dry matter per acre per year with an energy value of greater than 16 million Btu per ton.) However, it is not very likely that the proper conditions that would allow for the conversion of such large acreages will ever exist in Hawaii, just as, even in the most profitable years for sugarcane and pineapple, such large acreages never were placed in cultivation for a variety of reasons, the greatest being economic.

Assuming that those economic factors that prevented certain lands from being placed in intensive agriculture in the past would similarly prevent the same lands from being cultivated in energy crops, the focus of this investigation centers on those lands that presently or in recent history have been in intensive agriculture.

Since this study is interested primarily in energy crops, only those agricultural uses that have similar agronomic needs as energy crops are considered here (e.g., intensively cultivated crops are considered, whereas pasture land is not considered). The amount of land in intensively grown crops has varied substantially over this century; however, the trend generally has been downward. The number of acres in sugarcane, pineapple, and other crops reached a maximum in the 1930s (sugarcane acreage reached a maximum in 1933: 255,000 acres; in 1930, the land area in sugarcane, pineapple, coffee, and other crops was 352,000 acres). However, the amount of land in intensive cultivation 60 years ago probably has little relevance to the amount of land presently available for energy crop production; therefore, the amount of land in intensive cultivation in more recent history (over the last 25 years) is the focus of this investigation.

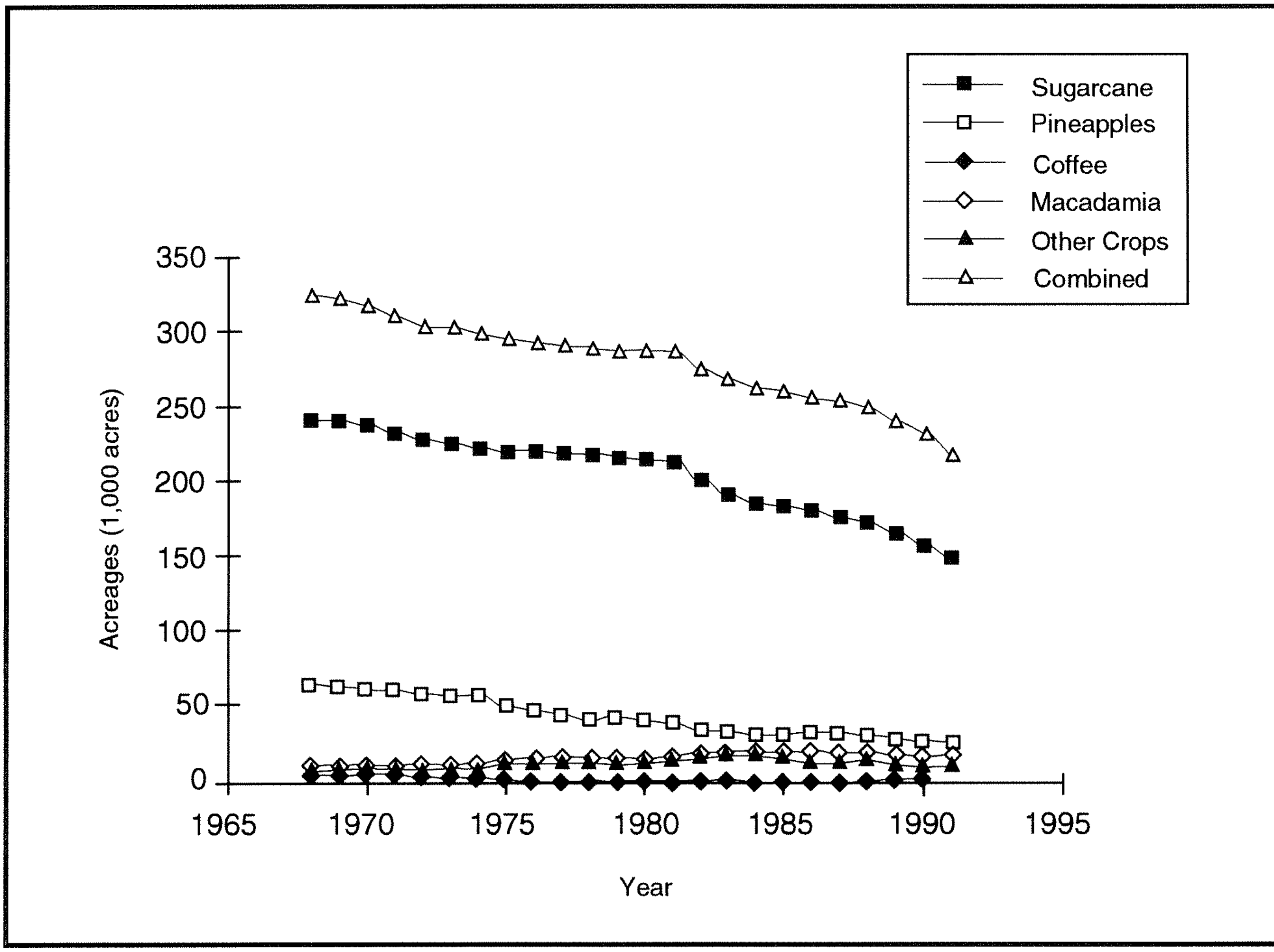
In 1968, the acreages in sugarcane and in all crops combined reached a local maximum, 242,000 acres and 326,000 acres, respectively. Over the last 25 years, the amount of land in agriculture has decreased steadily, owing to substantial reductions in sugarcane and pineapple acreages (Figure 7-2), from 326,000 acres in 1968 to less than 230,000 acres in 1993. Except for the island of Oahu, only a relatively small fraction of the land taken out of intensive cultivation has been reclassified (even on Oahu, much of the land taken out of sugarcane production over the past 25 years still sits fallow); therefore, the vast majority of the approximately 100,000 acres that has been taken out of agriculture could revert to agriculture if the economics of doing so were favorable (additional large tracts of unfarmed agricultural lands exist which could be used to replace lands switched from agriculture to other uses during the past 25 years).

Figure 7-3 compares lands in agriculture on the major islands in 1968 versus 1991. Over that period, acreage in agriculture declined on all islands; since 1991, additional large declines in sugar acreage have occurred.

Sugarcane represents the most abundant, high-energy-yielding crop in Hawaii and sugarcane production expertise and equipment are available in substantial amounts from the existing sugarcane industry. Therefore, sugarcane should be considered as a potential crop to harvest for production of fuels and electricity. Growing and harvesting high-yielding grasses and trees for conversion to electricity and fuel for transportation is another possible approach.

Figure 7-2

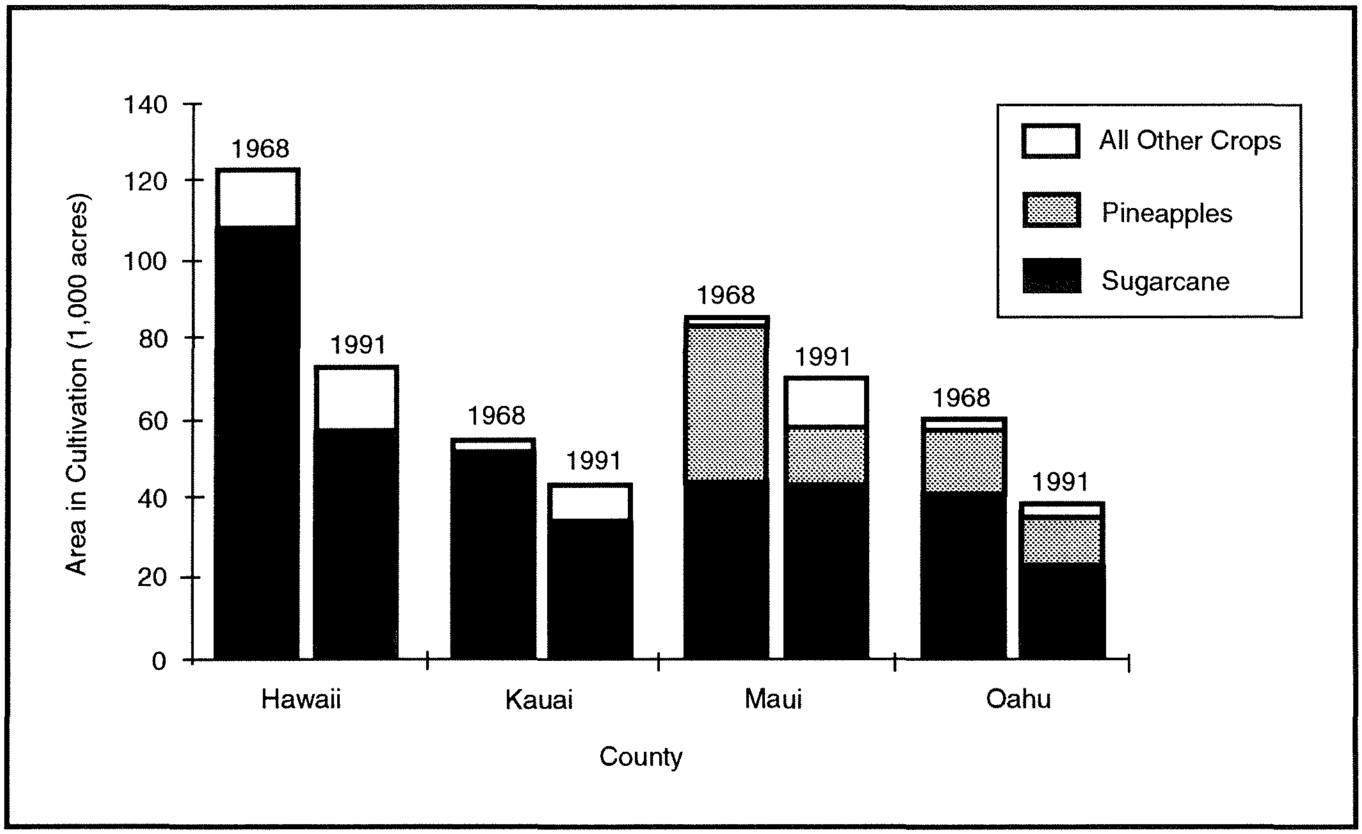
Land in Intensive Agriculture During Past 25 Years



Source: Hawaii Agricultural Statistics Service, various years.

Figure 7-3

Comparison of Acreages in Intensive Agriculture, 1968 versus 1991



Source: Hawaii Agricultural Statistics Service, various years.

Several scenarios for large-scale energy crop production are considered in this investigation:

(a) Use of sugarcane lands (approximately 156,000 acres in 1991) and sugarcane crop to produce fuel and electricity;

(b) Use of only those lands (or equivalent lands) taken out of intensive cultivation during the past 25 years for energy crop production, with the land presently in intensive cultivation remaining in the present crops, thus providing approximately 100,000 acres for energy crop production (the fact that these lands have been taken out of cultivation suggests that they are not as profitable as the lands included in (a), generally having lower yield potential than the above-mentioned parcels.)

(c) Conversion of all lands presently in intensive cultivation to energy crop production, thus providing nearly 230,000 acres for energy crop production (the fact that these lands remain in cultivation while others have been taken out of cultivation, suggests that they are the most profitable, generally having the highest yield potential; although high yielding and profitability are not necessarily synonymous.)

(d) Use of those lands (or equivalent lands) presently and previously (25 years ago) in intensive agriculture, nearly 330,000 acres, for energy crop production (note, while the vast majority of the lands in intensive agriculture during the past 25 years should be able to support the production of short-rotation intensive-culture energy crops, largely because the climatic and agronomic requirements for energy crops would be similar to those for sugarcane, a portion of the targeted lands, e.g., pineapple fields, might not be able to meet the high water demands for energy crops and therefore might not be well suited for the production of energy crops.)

Thus, four scenarios are considered in this investigation; they are summarized in Table 7-8.

Table 7-8

Land-Use Scenarios Considered

Number	Description
1	Use existing sugarcane lands (156,000 acres in 1991) and sugarcane crop to produce ethanol and electricity
2	Use lands equivalent to those lands removed from intensive cultivation since 1968 for energy crops (≈100,000 acres)
3	Convert lands presently in intensive cultivation to energy crops (nearly 230,000 acres)
4	Use lands equivalent to those lands in intensive cultivation in 1968 for energy crops (nearly 330,000 acres)

Considering the large number of workers in agriculture and others in the community who are supported by agriculture, and considering the large acreages of land involved, all of the above-mentioned scenarios could have very serious social and other implications. Furthermore, these scenarios would involve changes in the manner and location of extensive fuel and electricity production facilities for the state, and those changes also could carry serious social and other implications. Measurement of these implications would entail careful and extensive analyses of the various changes resulting plus the social, environmental, and other impacts of these changes; such analyses are clearly outside the scope of this investigation. While such implications could have far greater impact on society than those relating to energy production and use, this investigation focuses primarily on the energy aspects of producing fuels and electricity from biomass.

7.2.1.4 Energy Crop Yields Commercially Achievable

Since the available data on yield versus agronomic conditions (water, nutrients, etc...) are not precise enough to predict yield differences that would result from the small variations in agronomic conditions on the targeted lands, no attempt was made in this investigation to predict energy crop yields on a site-by-site basis.

Calculations performed by Hawaii Natural Energy Institute (HNEI) (Kinoshita, 1984) suggest that sugarcane grown commercially in Hawaii during the late 1970s and early 1980s produced an average dry-matter yield (prior to burning the crop in the field in preparation for harvesting and processing) of 17.5 tons per acre-year, comprising approximately 60 percent fiber and 40 percent sugar. (The yield of unburned sugarcane should not be confused with the commercial dry-matter yield, fiber and sugars, presently being reported by the Hawaiian sugar industry - the latter, the commercial yield, is determined after losses due to field burning and wet cane cleaning are incurred; it is assumed that similar practices would not be employed in the sugarcane-for-fuel option, thereby bringing sugarcane-for-fuel yields much closer to that of unburned cane.)

It appears feasible to achieve commercial yields of 18 to 25 tons per acre-year (dry basis) of banagrass and 9 to 15 tons per acre-year of tree crops if inputs (water and nutrients) are not limiting. (Management will play a major role in the actual yields in any biomass-for-energy operation.)

The commercial yields assumed in the present investigation are: for high-growth-potential regions (traditionally high-yielding areas) - 19 tons per acre-year for sugarcane, 22 tons per acre-year for banagrass, and 12 tons per acre-year for the tree crops; and for medium-growth-potential regions (traditionally lower-yielding areas) - 16 tons per acre-year for sugarcane, 18 tons per acre-year for banagrass, and 10 tons per acre-year for the tree crops. These assumed yields are summarized in Table 7-9.

The tree yields assumed are similar to those projected by many other investigators; e.g., based on ongoing work at BioEnergy Development Corporation on the island of Hawaii, Whitesell et. al. (1992) projected *eucalyptus* yields of 8-12 tons per acre-year for unirrigated sugarcane lands on that island, and in considering *eucalyptus* grown on 85,000 acres covering four islands, Phillips and co-workers (1993) projected harvestable yields of 11.4, 10.0, 10.2, and 9.3 tons per acre-year, for the islands of Hawaii, Kauai, Maui, and Molokai, respectively, averaging 10.2 tons per acre-year.

Table 7-9

Assumed Energy Crop Yields
(Tons/Acre-Year, Dry Basis)

Species	High-Growth Potential	Medium-Growth Potential
Sugarcane	19	16
Banagrass	22	18
Trees	12	10

As mentioned earlier, if efforts were made to maximize biomass yield rather than sugar yield, significantly higher biomass productivities with sugarcane appear possible. It is also likely that with aggressive breeding and selection, significantly higher commercial yields of the fiber crops (banagrass and trees) than those assumed in this investigation are achievable. Inherent to these yield projections is the assumption that inputs are not limiting. Indeed, whether sufficient inputs would be provided so that near-maximum yields can be achieved depends on the return farmers receive for the crop versus its cost of production. Cost studies performed by HNEI and coworkers for energy crops on Molokai suggest that if the market for energy crops is pegged at fossil fuel values, the production of intensively grown energy crops would not be feasible under most circumstances.

7.2.1.5 Amount Of Biomass Feedstock Potentially Producible

Based on the land-use scenarios listed in Table 7-8 and on the energy-crop yields listed in Table 7-9, Table 7-10 shows the amount of biomass feedstock that could be produced in the state.

7.2.2 OTHER FEEDSTOCKS

As mentioned in Section 7.2.1, biomass residues other than those from sugarcane or MSW represent a rather small energy resource; therefore, they are eliminated from further discussion. Only about one-half of the 1.2 million tons of MSW produced in the state annually is being converted into electricity; if the organic fractions of that resource were fully utilized, an additional 300,000-400,000 MWh per year of electricity might be producible. MSW is produced in much smaller quantities and is more dispersed on the neighbor islands than on Oahu and is generally handled differently. The feasibility of collecting and converting MSW into electricity in a manner similar to that being performed on Oahu, a topic of frequent study, is unclear. Sugarcane residues presently not used for boiler fuel represents another significant energy resource, approximately 600,000 tons annually. If the residues were recovered instead of burned in the field and then utilized for power generation along with bagasse, an additional 400,000-500,000 MWh of electricity might be producible annually (Kinoshita, 1991).

Table 7-10

Amount and Type of Feedstock Produced for Each Land-Use Scenario

Scenario[1]	Feedstocks Produced Annually[2]
1	830 thousand tons of fermentable sugars and 1.0 million tons of combustible fiber using existing commercial sugarcane crop on 156,000 acres[3]
2	1.6 million tons of sugarcane, 1.8 million tons of banagrass, or 1.0 million tons of tree crops using lands (≈100,000 acres) removed from intensive cultivation since 1968
3	4.3 million tons of sugarcane, 5.0 million tons of banagrass, or 2.7 million tons of tree crops using lands (nearly 230,000 acres) presently in intensive cultivation
4	5.9 million tons of sugarcane, 6.8 million tons of banagrass, or 3.7 million tons of tree crops using lands (nearly 330,000 acres) in intensive cultivation in 1968

Notes:
1) See Table 7-8 for description of land-use scenarios.
2) The nearly 230,000 acres presently in production are assumed to be high yielding while the 100,000 acres taken out of production since 1968 are assumed to be lower yielding (while this is an oversimplification of the yield potential of both tracts of land, the trend at least for sugarcane has been the closing or down-sizing of lower-yielding plantations while higher-yielding plantations have remained more stable.)
3) Sugars and fiber data based on commercial data for 1991 from HSPA (Hawaiian Sugar Planters' Association, 1992).

7.2.3 BIOENERGY CONVERSION TECHNOLOGIES; TRANSPORTATION FUEL AND ELECTRICITY PRODUCTIVITIES

The estimated amount of transportation fuels producible from a unit of biomass varies, depending on the type of fuel produced and the technology employed. The following liquid fuel products and conversion processes are considered in this analysis:

(1) ethanol produced from sugars in sugarcane via fermentation;

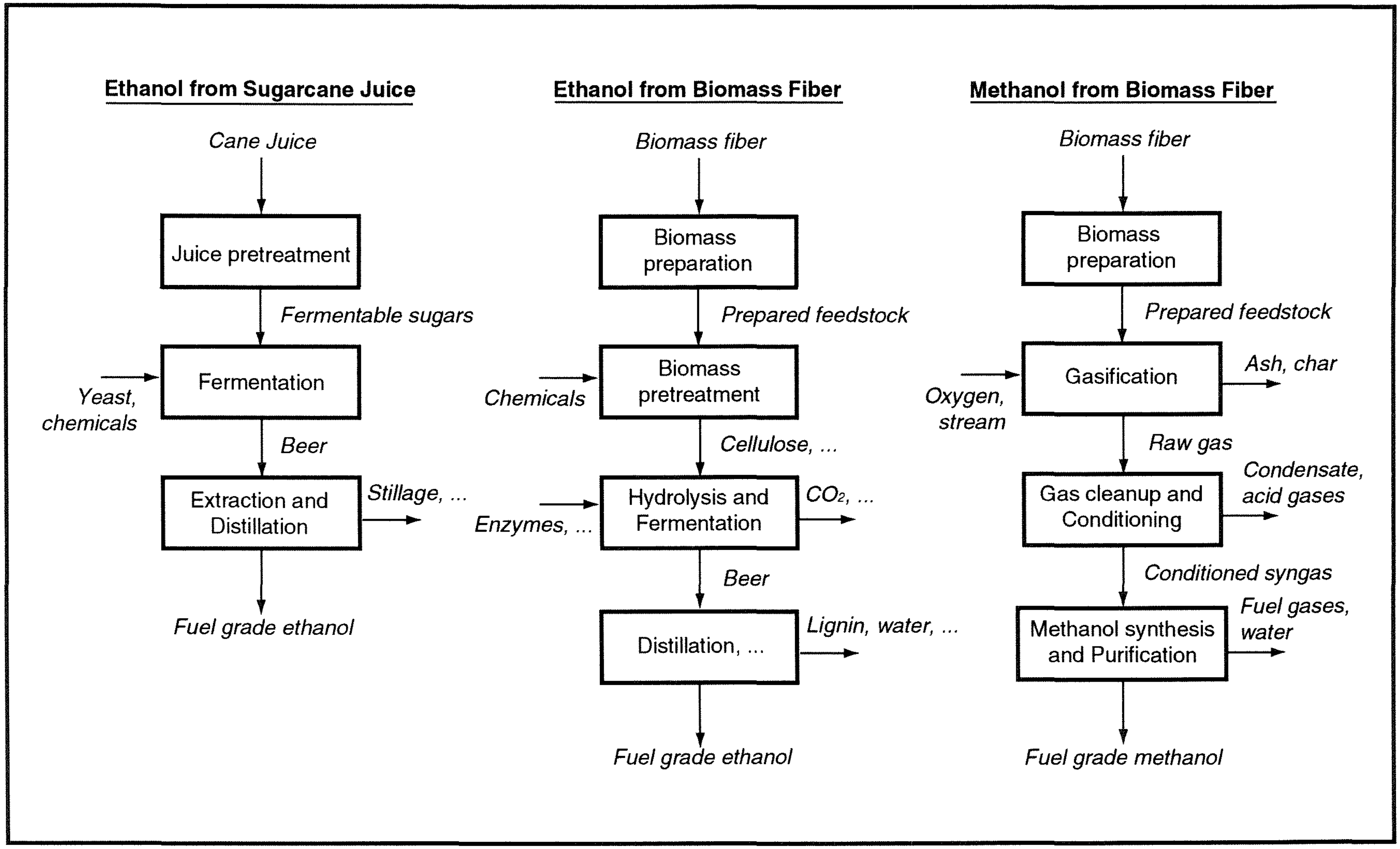
(2) ethanol produced from sugarcane sugars via fermentation and from sugarcane fiber via hydrolysis and fermentation; and

(3) methanol produced from biomass via partial oxidation (gasification) followed by catalytic synthesis (Figure 7-4).

The process of producing ethanol by fermentation of sugars has been well documented and subject to refinement for centuries; the production and utilization of ethanol from sugarcane molasses and other sugars in Hawaii has been the subject of numerous studies (e.g., Department of Business and Economic Development and Hawaiian Sugar Planters'

Figure 7-4

Alternative Biomass-To-Transportation Fuel Conversion Processes



Source: Hawaii Natural Energy Institute, 1994.

Association, 1987). Conversion of fiber into ethanol via hydrolysis and fermentation or into methanol via thermochemical conversion is still in the developmental stage; additional details on such processes are abundant in the literature (e.g., Wyman et. al., 1993; Takahashi, 1989).

The biomass-to-electricity technologies considered include:

(1) medium-pressure (greater than or equal to 800 psi) steam generation systems; and

(2) gas-turbine based combined-cycle systems.

The status of conversion technologies considered and their estimated conversion efficiencies are summarized in Table 7-11

Table 7-11

Status of Technology and Estimated Efficiencies for Selected Biomass-to-Energy Conversion Processes

Process/End Product	Status[1]	Anticipated Yield[2]
Biomass-to-transportation-fuels[3]		
• Ethanol from sugarcane sugars	Available	143 gal/ton[4]
• Ethanol from sugarcane (hydrolysis/fermentation)	<10 years	110 gal/ton[5]
• Methanol from Fiber (gasification/catalysis)	<10 years	150 gal/ton[6]
Biomass-to-electricity		
• Steam-turbine cycle using fiber	Available	1200 kWh/ton[7]
• Gas-turbine combined cycle using fiber	<10 years	1440 kWh/ton[7]

Notes:

1) Status denotes probable time span required to develop conversion technology to commercial stage.
2) Yield of transportation fuel or electricity per ton of dry matter in feedstock.
3) Does not include electricity-generation component. On basis of lower heating values, fuel equivalency is: 1 gallon gasoline = 1.5 gallons ethanol = 2.0 gallons methanol.
4) Steingass et. al., 1989.
5) Shleser, 1993a.
6) Takahashi, 1989.
7) Net power generation; 1200 kWh/ton = 25% efficiency and 1440 kWh/ton = 30% efficiency (averages of several published and unpublished values).

The data in Table 7-11 suggest that the yields of ethanol from sugarcane (110 gallons per ton dry matter) and methanol from plant fiber (150 gallons per ton dry matter) are comparable on a gasoline-equivalent basis, with both options yielding approximately 75 gasoline-equivalent gallons per ton of feedstock. Thus, the petroleum-displacement potential of either fuel would depend on the yield of the biomass feedstock used in manufacturing that fuel.

Biomass gasification with the addition of hydrogen prior to catalytic conversion into methanol has the potential to generate much greater quantities of transportation fuel from a given supply of biomass feedstock, approximately 330 gallons of methanol per ton of biomass fiber (Takahashi, 1989), than the other processes summarized above; however, that alternative requires the addition of large amounts of hydrogen, which, practically speaking, probably would need access to large amounts of inexpensive electricity (itself, an important energy product). Since hydrogen-augmented-biomethanol conversion was determined to be more costly than other biomethanol alternatives in spite of its dramatic yield advantage (Takahashi, 1989), the hydrogen-augmented-biomethanol alternative is not examined in this analysis (that conversion alternative is mentioned mainly to illustrate the significant quantity of transportation fuel that can be produced from biomass).

The conversion efficiencies for the two biomass-to-electricity options listed in Table 7-11 are averages of published and unpublished values (e.g., Larson and Williams, 1990; Electric Power Research Institute and SFA Pacific, 1993; Craig and Mann, 1993; Bain, 1994). The steam-turbine cycle, based on spreader-stoker boilers or fluidized-bed boilers, represents conventional biomass electricity generation technology. The gas-turbine combined cycle incorporates advanced, but commercially available aero-derivative or industrial gas turbine technology with existing steam generation technology. Although the power generation portions of gas-turbine based systems are commercial, their integration with biomass gasification and clean-up of the biomass-derived gas still are in the developmental stage. Scale-up and demonstration of those technologies presently are underway in Hawaii (Overend et. al., 1992) and elsewhere; technological risk is considered by most in the field to be moderate. Given the relatively low developmental risk of such technology and the relatively short lead time anticipated for commercializing the technology, only the gas-turbine-based option is considered in the following discussion on electricity cost.

7.3 ESTIMATED PRODUCTION COST OF TRANSPORTATION FUELS AND ELECTRICITY FROM HAWAII BIOMASS

7.3.1 COST OF BIOMASS FEEDSTOCKS

Projected feedstock costs are very site specific, depending on such factors as scale of operation, the amount of irrigation water needed and its cost, and the type of harvesting and transporting system employed. Therefore, it is not surprising that whereas there appears to be some consensus on likely commercial yields of biomass-for-energy crops, there seems to be much less agreement on the cost of growing, harvesting, and transporting energy crops to the biomass conversion plant. The projected cost of producing and delivering biomass feedstocks to a central receiving point varies widely (e.g., Hubbard and Kinoshita, 1993; Osgood and Dudley, 1993; Phillips et. al., 1993; Troy, 1982; Whitesell et. al., 1992) from approximately $30 per ton (dry basis) to nearly $100 per ton.

For the comparisons in this chapter[2], it was agreed to use three different feedstock costs - low, intermediate, and high - as the bases for estimating transportation fuels and electricity production costs. The three feedstock costs (dry basis, free-on-board (FOB) conversion plant gate) assumed for this investigation are: $40 per ton (low); $50 per ton (intermediate); and $60 per ton (high). The feedstock is assumed to be delivered to the conversion facility in partially processed form (e.g., prepared cane, chopped banagrass, or woodchips).

7.3.2 LIQUID FUEL COST

7.3.2.1 Ethanol

In this investigation, the cost of producing ethanol from sugarcane is extrapolated from Shleser (1993a and 1993b). In the study leading to these reports, developers of competing ethanol-from-biomass technologies[3] provided cost data for the following categories: biomass feedstock; chemicals; utilities; general and administrative; labor and benefits; property taxes and insurance; and capital. To evaluate the competing technologies and their economics on a comparative basis, scaling factors were applied to the data provided by the developers to project ethanol costs from conversion facilities having capacities of 5 mgpy and 25 mgpy. The ethanol production costs (excluding feedstock cost) for the competing technologies are plotted in Figure 7-5. Also plotted in Figure 7-5 is an averaged ethanol conversion cost versus capacity curve, calculated from the 5 mgpy and 25 mgpy projections for the seven competing technologies, using the scaling factors assumed by Shleser. The cost-versus-scale curve in Figure 7-5 forms the basis of the ethanol costs used in this investigation.

7.3.2.2 Methanol

Price estimates for methanol from biomass are summarized in Table 7-12. Base prices for methanol are derived from calculated unit prices of methanol at the plant gate, adjusted to the following base conditions: methanol yield equals 150 gallons per ton of feedstock (Takahashi, 1989); 1991 dollars. The base prices presented in Table 7-12 include estimates by HNEI (Takahashi, 1986; Takahashi, 1989) for three production scales and estimates by the National Renewable Energy Laboratory (NREL) (Bain, 1993) for two scales. The price figures presented at the bottom of Table 7-12 are adjusted to exclude feedstock costs. These final price figures form the basis for the estimated price of methanol produced from biomass feedstocks delivered to the conversion facility at the range of feedstock costs considered in the present analysis.

It must be recognized that the original price figures given in Table 7-12 were derived in terms of the particular set of conditions selected by the investigators of the individual studies. Some of those conditions have been normalized by use of the adjustments indicated in that table. Other assumptions used could prove to be inaccurate when an actual plant is constructed

[2] In the alcohol production cost scenarios of Chapter 8, feedstock costs are based on a range of estimates of commercially-achievable yields and costs.

[3] Including simultaneous saccharification and fermentation; acetone extraction and fermentation; steam explosion; ammonia explosion with recycling; acid hydrolysis and genetically engineered fermentation; concentrated acid hydrolysis with recycling; and concentrated acid hydrolysis.

and operated, but no adjustments have been made for such variations. For example, the 1989 HNEI study assumes an integrated methanol production system involving a geothermal power plant providing electricity at 4.22 cents per kWh and an independent oxygen plant adjacent to the methanol plant, providing oxygen at $20 per ton. It is likely that any variations in actualizing such elements would lead to increased methanol prices. On the other hand, variations in other assumptions could lead to decreased prices (e.g., assumptions that there would be no tax credits for the project and that no by-product credit would be obtained for the carbon dioxide produced). The adjusted unit price of methanol, less feedstock cost, FOB conversion plant gate (bottom row of numbers in Table 7-12), is plotted in Figure 7-6. The best-fit curve forms the basis of the methanol prices used in this investigation.

7.3.2.3 Comparison Of Fuel Costs

The costs of producing ethanol and methanol from biomass are presented in Table 7-13 for selected cases to illustrate the influences of scale of conversion facility and cost of feedstock on the overall fuel cost. The cost of ethanol is based on the cost curve in Figure 7-5, with the cost of the feedstock included. The cost of methanol is based on the best-fit price curve in Figure 7-6. Three feedstock costs and three different production scales, representing small, medium, and large plants (three sizes for ethanol production and three sizes for methanol production) are assumed in the analysis leading to Table 7-13.

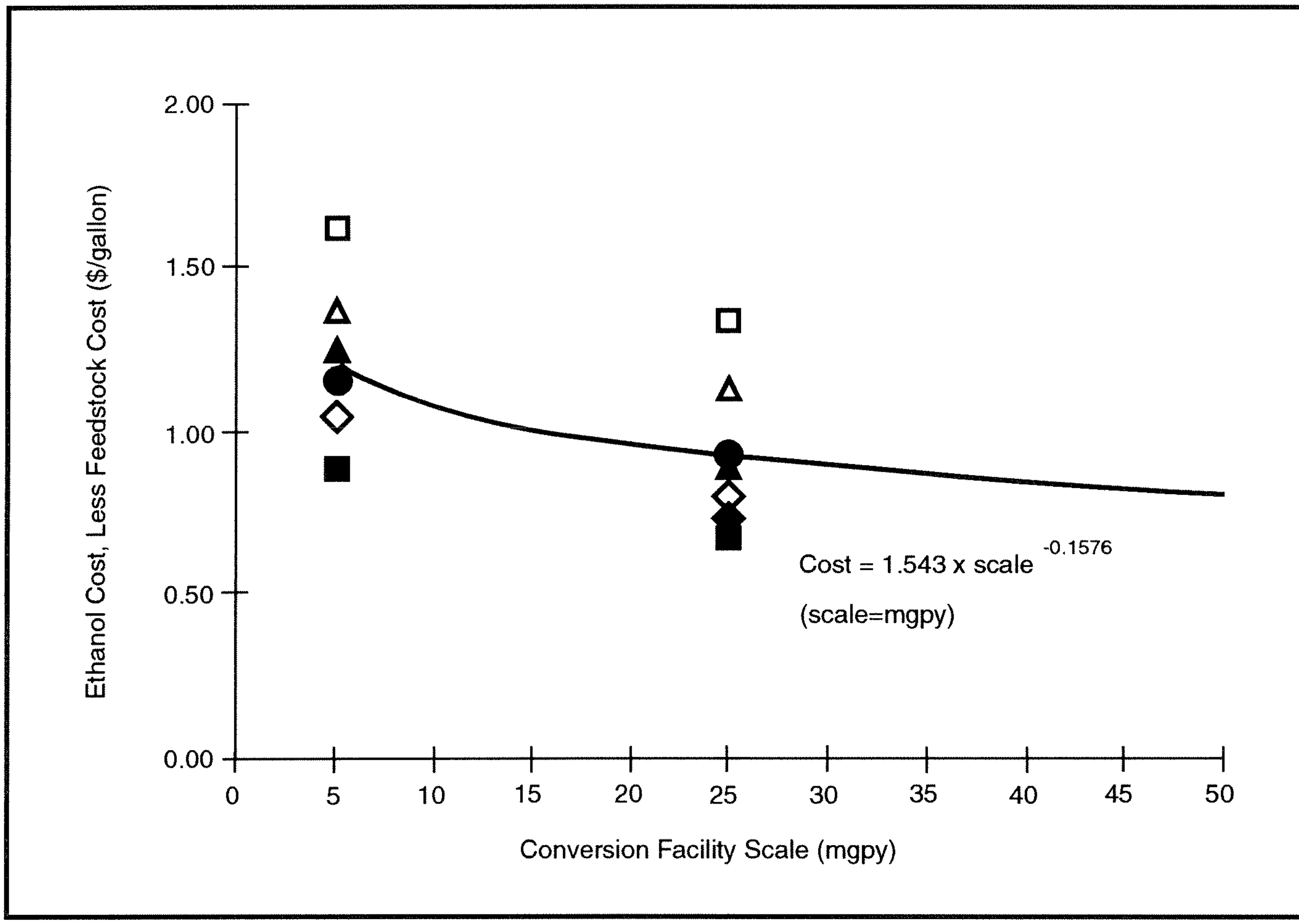
Within the range of parameters considered in Table 7-13, the plant-gate cost for ethanol varies from $1.20 to $1.74 per gallon ($1.79 to $2.61 per gasoline-equivalent gallon) and that for methanol varies from $0.67 to $1.24 per gallon ($1.35 to $2.48 per gasoline-equivalent gallon), increasing as the scale of the plant decreases and the cost of the feedstock increases. Although the gasoline-equivalent cost for methanol appears to be somewhat lower than that for ethanol, the production size required to approach economic scales in methanol plants is much larger than for ethanol plants (the costs of both fuels are comparable when evaluated at equivalent production scales). Also, the feedstock supply infrastructure for the ethanol-from-sugarcane option already is in place; whereas the feedstock supply infrastructure for methanol production must be established whether the feedstock consists of banagrass or trees.

It should also be noted that other studies (e.g., Wyman et. al., 1993) have projected that with scale-up of existing technology, ethanol from biomass should have a plant-gate cost of roughly $1.00 per gallon, lower than even the lowest cost shown in the preceding table ($1.20 per gallon for ethanol produced in a large plant from biomass costing $40 per ton); those same studies project even lower ethanol production costs with anticipated improvements in technology.

Previous studies have suggested numerous byproducts that might potentially accrue from alcohol production which would offset production costs. While byproduct credits are not considered in this investigation, their potential to significantly reduce the net cost of producing alcohol fuels from biomass is acknowledged; indeed, a more detailed study of their impact on the economics of alcohol fuels production seems warranted.

Figure 7-5

Production Cost of Ethanol-from-Sugarcane, Less Feedstock Cost



Source: Shleser, 1993a.

Note: Data symbols differentiate seven technologies.

Table 7-12

Estimated Price for Methanol from Biomass

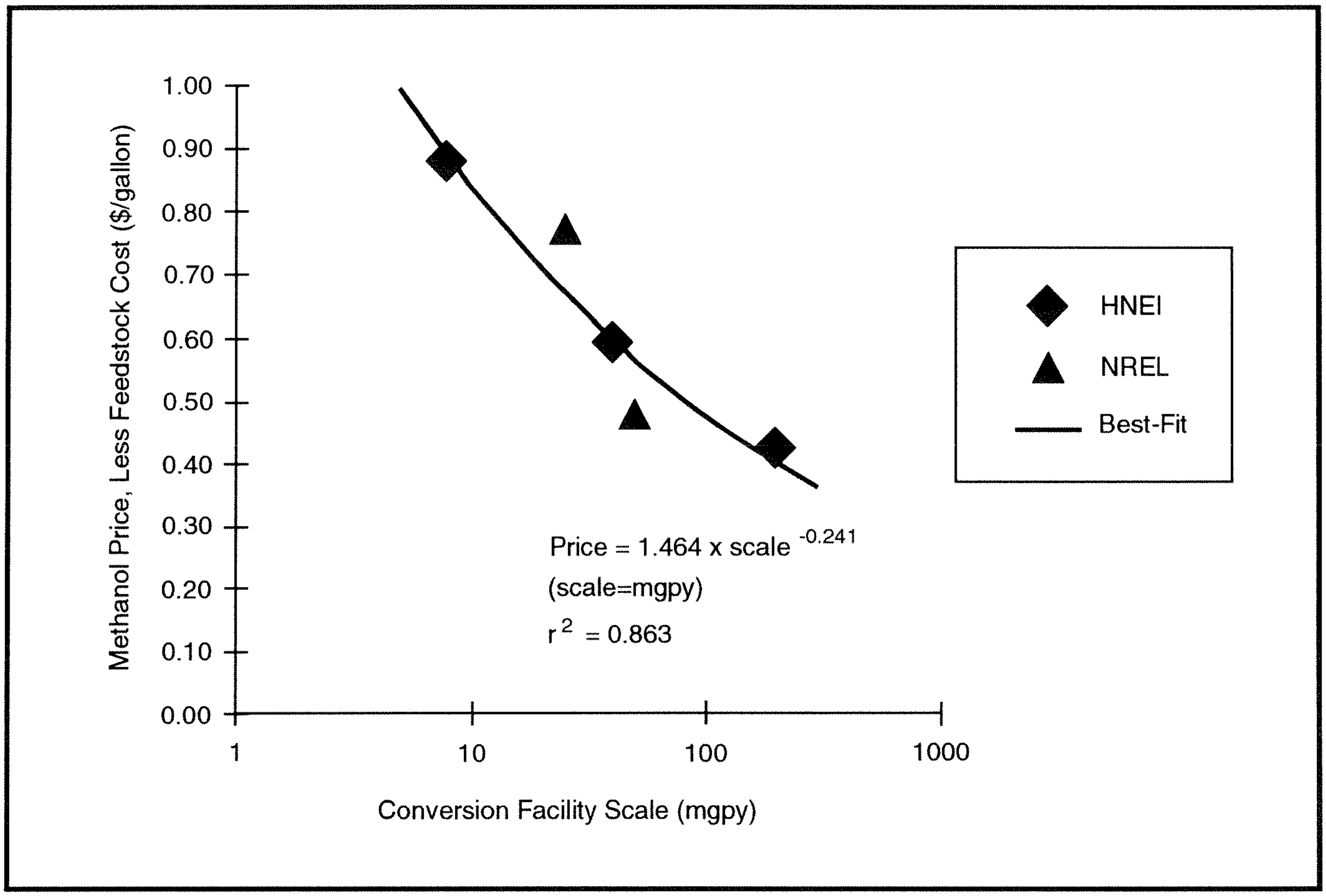
Case[1]	HN1	NR1	HN2	NR2	HN3
Reference date of price values	1988	1991	1988	1991	1988
Scale (mgpy)	7.8	25	40	50	200
Feedstock cost ($/ton)	30	23.59	30	24.49	30
Methanol yield (gal/ton)	150	185.7	150	185.7	150
Unit price[2] ($/gal)	1.00	0.75	0.74	0.52	0.59
Adjusted (Base) price, less feedstock cost[3] ($/gal)	0.89	0.77	0.60	0.48	0.43

Notes:

1) "HN" denotes 1989 HNEI study (Takahashi, 1989); "NR" denotes 1993 NREL study (Bain, 1993).
2) Original numbers from 1993 NREL study and 1989 HNEI study, with smaller scale plants of the HNEI work (7.8 and 40 mgpy) recalculated from 1986 prices (Takahashi, 1986) using updated capital and operating costs from 1989 study, plus plant cost index adjustment.
3) Adjusted to Base conditions: Methanol yield = 150 gal/ton feedstock (assumes that methanol cost is inversely proportional to yield) and 1991 dollars, adjusted according to Chemical Engineering plant cost index for overall cost (Chemical Engineering, 1990); feedstock cost is deleted to make final price feedstock-price-neutral.

Figure 7-6

Adjusted Methanol Price, Less Feedstock Cost



Source: See Table 7-12.

Table 7-13

Estimated Unit Cost of Alcohol Fuels from Biomass, FOB Conversion-Facility Gate

	Plant Scale					
	Small		Medium		Large	
Ethanol from Sugarcane						
Production						
Fuel production (mgpy)	5		2		50	
Biomass feedstock(tpd)[1]	138		68		1380	
Plant-gate cost (equivalent)[2]	$/gallon	$/gallon gasoline	$/gallon	$/gallon gasoline	$/gallon	$/gallon gasoline
@ $40/ton feedstock	1.56	2.34	1.29	1.94	1.20	1.79
@ $50/ton feedstock	1.65	2.48	1.38	2.08	1.29	1.93
@ $60/ton feedstock	1.74	2.61	1.47	2.21	1.38	2.07
Methanol from Fiber						
Production						
Fuel production (mgpy)	10	10	5		200	
Biomass feedstock(tpd)[1]	202	202	101		4040	
Plant-gate cost (equivalent)[2]	$/gallon	$/gallon gasoline	$/gallon	$/gallon gasoline	$/gallon	$/gallon gasoline
@ $40/ton feedstock	1.11	2.21	0.84	1.67	0.67	1.35
@ $50/ton feedstock	1.17	2.35	0.90	1.81	0.74	1.48
@ $60/ton feedstock	1.24	2.48	0.97	1.94	0.81	1.62

Notes:
1) Assumes ethanol-from-sugarcane yield = 110 gal/ton (dry basis); methanol-from-fiber yield = 150 gal/ton (dry basis); assumes 330 operating days per year.
2) Fuel equivalency based on equivalent lower heating values. Lower heating values used (Davis and Strang, 1993): ethanol = 76,000 Btu/gallon; methanol = 56,800 Btu/gallon; gasoline = 114,000 Btu/gallon (average of range of values used for gasoline); thus, 1 gallon gasoline = 1.5 gallons ethanol = 2.0 gallons methanol.

Feedstock is a major component in the overall cost of producing transportation fuels from biomass. Based on the conversion efficiencies assumed in this analysis, 110 gallons of ethanol per ton of sugarcane dry matter and 150 gallons of methanol per ton of fiber, each $10 per ton (dry basis) increment in feedstock cost translates to a 13 cents per gallon (gasoline-equivalent basis) differential in ethanol or methanol fuel cost. The scale of the conversion facility (determined largely by the size of the biomass plantation that serves the facility and the crop yield) and feedstock cost both influence the unit cost of alcohol fuel significantly. It is likely that at intermediate scales of production, savings accrued in increasing plantation and facility size would be offset by higher costs in transporting biomass longer distances to the conversion facility.

7.3.3 ELECTRICITY COST

Only gas-turbine combined cycle systems, presently under development, are considered in estimating the cost of biomass-derived electricity. The cost is based on estimates from four independent technoeconomic evaluations of biomass gasifier/gas-turbine combined-cycle electricity generation systems. The four separate evaluations are described in a detailed comparative study by Craig and Mann (1993). The same four systems were reevaluated by Bain (1994); the results of the reevaluation, less feedstock cost, are summarized in Table 7-14.

Explanations for the substantial differences in the four estimates of electricity generation cost in Table 7-14 are offered by Craig and Mann (1993). The average values for unit cost and scale ($0.054 per kWh at 56 MW) in Table 7-14 are used as the basis of the present investigation. A comparison of the projected costs for eleven biomass power systems (Craig and Mann, 1993) suggests that unit cost ($ per kWh) scales roughly with capacity (MW) according to a 0.7 power. That power factor is applied to the aforementioned base cost and scale ($0.054 per kWh at 56 MW) to project electricity costs, less feedstock cost, for electricity generation facilities of different sizes.

In parallel with Table 7-13, for the liquid fuels, the cost of producing electricity from biomass is presented in Table 7-15 for selected cases to illustrate the influences of scale of generation facility and cost of feedstock on the overall cost of producing electricity.

Table 7-14

Technical and Cost Data for Four Biomass Integrated Gasification Combined Cycle Power Systems[1]

	EPRI	Tecogen	Ebasco	NREL	Average
Facility Size (MW)[1]	50	50	64	60	56
Capital Cost ($/kW)[1]	3,005	1,850	1,706	1,680	2,060
Efficiency (%)	28	29	29	37	31
Electricity Cost (cents/kWh)[1]					
Capital	4.2	2.6	2.3	2.3	2.9
O&M	4.1	2.1	1.7	2.4	2.6
Total (less feedstock)	8.3	4.7	4.0	4.7	5.4

Source: Bain, 1994
Note:
1) Net power generation; all figures are rounded.

Table 7-15

Estimated Unit Cost of Electricity from Biomass

	Plant Scale		
	Small	Medium	Large
Production			
Electricity generation (MW)	10	50	100
Biomass feedstock (tpd)[1]	167	833	1,670
Plant-gate cost (cents/kWh)			
@ $40/ton feedstock	11.8	8.4	7.3
@ $50/ton feedstock	12.5	9.1	8.0
@ $60/ton feedstock	13.2	9.8	8.7

Note:
1) Assumes electricity-from-fiber yield = 1440 kWh/ton (dry basis).

7.4 TOTAL AMOUNT AND COST OF TRANSPORTATION FUELS AND ELECTRICITY PRODUCIBLE FROM BIOMASS

7.4.1 DISTRIBUTION OF LAND FOR BIOENERGY CONVERSION

The limited scope of this investigation does not permit precisely matching discrete tracts of land with conversion systems so that crop production/delivery are optimized with fuel or electricity generation. Instead, in this investigation, the lands and the crops grown on those lands are assumed to be distributed evenly between the conversion plants on each island. The assumed distributions of lands and crops to biomass conversion facilities are summarized in Table 7-16.

7.4.2 TRANSPORTATION FUELS PRODUCTION

The amounts of alcohol fuels and the unit costs of fuels producible from sugarcane (ethanol), and banagrass or tree crops (methanol), calculated on the basis of the land allocations presented in Table 7-16, the feedstock amounts in Table 7-10, and the intermediate feedstock cost of $50 per ton, are summarized in Table 7-17.

7.4.3 ELECTRICITY PRODUCTION

The average size of electrical generation facility, and the amount and unit cost of electricity producible from banagrass or tree crops, calculated on the basis of the land allocations presented in Table 7-16, the feedstock amounts in Table 7-10, and the intermediate feedstock cost of $50 per ton, are summarized in Table 7-18.

7.4.4 SUMMARY OF STATEWIDE PRODUCTION OF TRANSPORTATION FUELS AND ELECTRICITY FROM BIOMASS

Because banagrass is higher yielding than trees, more banagrass can be delivered from a tract of land to a given conversion facility than woodchips. The higher tonnage in turn allows the conversion facility to achieve greater economies of scale with banagrass than with woodchips, and consequently the cost of methanol or electricity would be lower with banagrass (as seen in Table 7-17 and 7-18). However, if woodchips can be delivered to the conversion facility at a lower price than banagrass, then the lower price for the woodchip feedstock might offset its higher conversion cost and make the overall cost of biofuel from woodchips comparable to or even lower than the overall cost of biofuel from banagrass.

Based on the land-use scenarios summarized in Table 7-8, the crop yield estimates presented in Table 7-9, and the conversion efficiencies summarized in Table 7-11, it appears that the amounts and costs of transportation fuels or electricity producible from biomass statewide are as presented in Table 7-19. The reader is reminded that these are gross estimates based on simplifying assumptions, developed solely for the purposes of providing order-of-magnitude estimates for this project; actual crops, yields, and costs could vary significantly depending on site, weather conditions, financing, sales of byproducts, market conditions, status of technology, and many other factors.

Table 7-16

Hypothetical Distribution of Land for Bioenergy (Biomass to Ethanol, Methanol, or Electricity) Conversion

Scenario[1]	Number of Facilities: Average Crop Acreage Per Facility (1,000 acres)				
	Hawaii	Kauai	Maui[2]	Oahu	Total Facilities: Average Acreage
1	3:19	4:9	3:14	2:12	12:13
2E	3:17	1:11	1:17	1:22	6:17
2M	2:25	1:11	1:17	1:22	5:20
3E	4:18	5:9	4:18	2:19	15:15
3M	2:37	2:22	2:35	2:19	8:28
4E	6:21	5:11	4:22	3:20	18:18
4M	3:41	2:27	2:44	2:30	9:36

Notes:

1) See Table 7-8 for description of land-use scenarios. "E" denotes sugarcane to ethanol conversion or biomass fiber (banagrass or tree crop) to electricity conversion; "M" denotes biomass fiber (banagrass or tree crop) to methanol conversion.
2) Data for Maui island includes entire Maui county which comprises the islands of Maui, Molokai and Lanai. Therefore, Maui island figures are slightly overestimated.

Table 7-17

Amounts and Unit Costs of Alcohol Fuels Producible from Biomass[1]

Scenario	Hawaii	Kauai	Maui	Oahu	Average
	Average ethanol production per facility from sugarcane (mgpy)				
1	10	7	13	10	10
2	29	19	30	38	29
3	38	19	37	40	32
4	40	22	44	39	36
	Average unit cost of ethanol produced from sugarcane ($/gal)				
1					
2	1.36	1.43	1.36	1.32	1.37
3	1.32	1.43	1.33	1.32	1.36
4	1.32	1.40	1.30	1.32	1.34
	Average methanol production per facility from banagrass: trees (mgpy)				
1	N/A	N/A	N/A	N/A	N/A
2	67:37	28:16	46:26	59:33	54:30
3	121:66	73:40	116:64	63:34	93:51
4	125:69	87:48	140:76	92:51	113:62
	Average unit cost of methanol produced from banagrass: trees ($/gal)				
1	N/A	N/A	N/A	N/A	N/A
2	0.86:0.95	0.99:1.09	0.91:1.00	0.88:0.97	0.90:0.99
3	0.79:0.87	0.85:0.94	0.80:0.87	0.87:0.96	0.83:0.91
4	0.79:0.86	0.83:0.91	0.78:0.85	0.83:0.90	0.80:0.88

Note:
1) On basis of lower heating values, fuel equivalency is: 1 gallon gasoline = 1.5 gallons ethanol = 2.0 gallons methanol.

Table 7-18

Generation Scale, Amount and Unit Cost of Electricity Producible from Biomass

Scenario	Hawaii	Kauai	Maui	Oahu	Average
	Average output per generation facility using banagrass: trees (MW)				
1	N/A	N/A	N/A	N/A	N/A
2	54:30	35:19	56:31	71:40	54:30
3	73:40	35:19	71:39	76:42	60:33
4	76:42	42:23	85:46	75:41	68:37
	Average annual production per facility using banagrass: trees (million kWh)				
1	N/A	N/A	N/A	N/A	N/A
2	430:239	273:152	443:246	565:314	429:238
3	581:317	281:153	559:305	604:329	478:261
4	602:331	336:184	670:367	591:324	541:297
	Average unit cost of electricity produced from banagrass: trees (cents/kWh)				
1	N/A	N/A	N/A	N/A	N/A
2	8.9:10.0	9.7:10.9	8.9:9.9	8.5:9.5	9.0:10.0
3	8.5:9.4	9.7:10.9	8.5:9.5	8.4:9.4	8.9:9.9
4	8.4:9.4	9.3:10.5	8.2:9.2	8.4:9.4	8.6:9.7

Table 7-19

Summary of Statewide Production of Transportation Fuels (Fuel Amounts and Unit Costs Are Shown on Gasoline-Equivalent Bases) and Electricity from Biomass[1]

	Acreage	Ethanol[1,2]		Methanol[1,2]		Electricity[2]	
Scenario	(1000 ac)	(mgpy)	($/gal)	(mgpy)	($/gal)	(MW)	(cents/kWh)
1	156	79	*	N/A	N/A	N/A	N/A
2	99	116	2.05	134:74	1.80:1.98	325:180	9.0:10.0
3	226	315	2.04	374:204	1.66:1.82	906:494	8.9:9.9
4	326	432	2.01	507:278	1.61:1.76	1230:674	8.6:9.7

Notes:
1) Fuel equivalency assumed: 1 gallon gasoline = 1.5 gallons ethanol = 2.0 gallons methanol.
2) Amounts and costs refer to ethanol from sugarcane, and methanol and electricity from banagrass: trees.
*) No data available from Hawaii Natural Energy Institute.